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OBJECTIVES, PROGRESS, AND PLANS IN BRIEF

A. TASK OBJECTIVES

The goal of our research in distributed computing is to evolve fundamental concepts as well as implementation techniques for improving system performance by judicious runtime distribution of functions to processors and to levels of a hierarchical operating system. This optimal distribution of computing tasks among the various processors in a network or among the many levels of a hierarchical operating system in a single computer is a critical issue in current and future industrial, military, and educational computer systems. For example, host/satellite configurations (consisting of a large-scale time-shared host computer and a set of small but "intelligent" mini-computer satellites) and networks of heterogeneous mainframe or minicomputer systems, will continue to grow in importance.

Our objective is to develop tools for the applications programmer that allow both the estimation of performance improvements of potential migrations, either horizontal (inter-processor) or vertical (intra-processor, between layers of the hierarchical system) and the implementation of the most promising migrations. Furthermore, the resultant division of labor must represent a cost-effective, reliable use of the selected configuration. Through cycles of design and experimental validation/tuning, we expect to produce production tools and results potentially applicable to a range of modern distributed architectures.

B. PROGRESS

During this past contract period, significant progress was made towards both a better understanding of fundamental problems involved in horizontal and vertical migration, and the development of tools needed for analyzing these problems and actually performing migrations. The prototype Interconnected Processing System (ICOPS) was used to run a number of scenarios for a real-time (graphics) applications program under varying loading conditions of the IBM 360/67 time-shared host. Runtime execution data gathered was plugged into a "max-flow, min-cut" commodity network graph model developed by our research partner, Professor Harold Stone of the University of Massachussetts, and implemented at Brown. The optimal distribution of modules between the host and the runtime satellite was then calculated for varying load conditions, and experimentally verified by runtime migration and data gathering. We now feel that we have essentially solved the two processor distributed computing problem, using cur unique ICOPS tools which became available this past year. These consist of an ALGOL-W compiler for both host and satellite which can make symbol table information available, a runtime monitor for communicating between modules (both inter- and intra-processor), gathering statistics and performing migrations, and a network analysis program for predicting optimal distributions.

The only problem that still needs to be solved before a fully automated, dynamic load distribution system can be made available is that of predicting host CPU availability as a function of easily measured parameters. We have found that the usual indicators such as numbers of users logged on, average queue lengths, etc., are not good predictors for determining relatively stable time intervals of CPU availability at a given level. Also, no exact solution using commodity networks for more than two processors has been developed, so we expect to continue our work with Dr. Jeff Buzen of Harvard and BGS Systems in the area of Queueing Network models for multiple dedicated satellites.

A successful two day Workshop in Distributed Processing was held at Brown in August to consider related projects in multiprocessor dynamic loadsharing. Some twenty invited participants produced papers. Also, we collected a bibliography of more than 150 entries, and produced transcripts for the <u>Computer Architecture Newsletter</u>. Transcripts of the first three sessions were published in vol. 5, no. 5, December, 1976; the transcripts of the last sessions will appear in March, 1977. A special issue of IEEE's <u>Computer</u> magazine, to be published in January, 1978, will carry session transcripts and invited papers.

In the area of vertical migrations the STRUCT system was used for analyzing our satellite's operating system to improve its performance in the context of several frequently used applications programs. We developed a methodology this past year for systematically examining candidates for migration and then predicting the performance improvement for the most promising candidates, primarily based on having the system compute Instruction Fetch and Decode overhead which could be saved. We also started to understand the types of interactions between migrations which occur because the CPU-use of levels in a hierarchy changes drastically when functions in lower levels on which they depend are migrated. Because of these interactions, vertical migration appears to be intrinsically and substantially more difficult than horizontal migration and we need to do much more analysis and experimentation before we can develop production tools like ICOPS.

Finally, in the area of high performance graphics, we produced an extremely powerful hierarchical picture data structure. Our homegrown matrix and data structure processor, the SIMALE, can interpret it at thirty frames per second to achieve full motion dynamics for well over a thousand 2D, 3D, or 4D vectors, as well as "logical zooming" via "extents." Extents are alternative representations of picture components, with varying levels of detail as a function of the amount of magnification of the total picture. Real-time, user-controlled animation of complex scientific subjects is facilitated by using extents.

C. PLANS IN BRIEF

Our proposal for the continuation of this research program for the twelve-month period of April 1, 1977 - March 31, 1978, has been submitted.

In the area of dynamic horizontal migration for host/satellite systems, we will tackle the one remaining problem, that of determining host CPU availability. We will probably have to modify Brown's production operating system (CP/CMS) in order to insert some probes which can give us meaningful quantitative input to our network and queueing models.

In the area of vertical migration, we will add additional analysis software to make STRUCT a more powerful predictor of performance improvement. At the same time, we will start a new phase, the paper design of a hierarchical operating system, to help understand what factors were involved in making a function intrinsically migratable, and how one assesses secondary interactions between migrated functions. We will also look at a variety of modeling disciplines to see which one might help us to be more analytical and quantitative about vertical migrations.

Finally, under the aegis of NSF's Office of International Programs grant #OIP73-02268 A02, entitled "Man-Machine Synergy," we will continue our collaboration with the Hungarian Academy of Science's Computer and Automation Research Institute. We will start the second phase of a Computer Aided Design research project in interactive blanking die design. We plan to use this demanding application as a typical useful production program to test, benchmark, and improve our sophisticated facilities: high level languages and graphics primitives, host/satellite dynamic distributed processing, lower level fixed function multiprocessing for real-time ultradynamic graphics. Only by taking a real application will we be able to assure ourselves that our distributed processing tools and methodologies work and are cost-effective; there can be no technology transfer to other groups and configurations until such a convincing demonstration has taken place.

Also, during the coming year, we plan to help Brown's Bio-Medical Department with their NIH grant, #NS 13031-01, "Structure-Function Analysis of Single Cortical Neurons". Using our powerful graphics facilities in conjunction with ICOPS, they plan to reconstruct three dimensional images of cortical neurons from serial sections. These images will then be used to analyze the synapses on each segment of the dendritic tree. The input phase of the system is being implemented on our graphics satellite as a stand-alone application, but the full analysis package will require the computing facilities available on the Brown 360 host as well. ICOPS will allow the applications programmer to use the full power of dynamic load balancing to achieve optimal response time and minimize computing costs.

## PUBLICATIONS, REPORTS, AND THESES FOR THE PERIOD

### A. PUBLISHED PAPERS

"Experience with Distributed Processing on a Host/Satellite Graphics System", J. Michel and A. van Dam, ACM SIGGRAPH 10, 2, July, 1976.

### B. REPORTS

"SIMALE Assembler, User's Guide", R.W. Burns, January, 1976.

"ALGOL-W Reference Manual", C. Sorgie, Project Manual, July, 1976.

"Programmer's Guide to ALGOL-W", H. Koslow, Project Manual, August, 1976.

"Floating Point Processor for BUGS", Pal Verebely, Project Manual, August, 1976.

"The SIMALE Standard Graphics Package", Preliminary Description, R.W. Burns and H.H. Webber, December, 1976.

"Brown University Graphics System (BUGS) Overview", Project Manual, updated December, 1976.

C. THESES

"An ALGOL-W/360 to M4A Cross Compiler", C. Sorgie, Masters Thesis, Brown University, June, 1976.

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